Evaluation of Elastic Modulus Properties of Flexible Pavement at Korea Expressway Corporation Test Road

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ABSTRACT

The objective of this paper was to present a seasonal effect on elastic modulus of flexible pavements based on the Korea Expressway Corporation Test Road. To this end, asphalt sections were selected from the Korea Expressway Corporation Test Road, which was built in 2002. A series of Falling Weight Deflectometer (FWD) tests were conducted at each section at different seasons. ELMOD program was adopted to estimate moduli of pavement layers based on FWD measurements. Both air and pavement temperatures were collected from embedded sensors and were considered into back-calculation procedure. It was shown that seasonal variations of elastic moduli were dependent upon layer thickness and quantified for flexible pavement design.

1. INTRODUCTION

In flexible pavement design, response of subgrade to dynamic traffic loads has been measured as soil support value, bearing ratio, and most recently as elastic modulus or resilient modulus (M_R). AASHTO 1986 [1] recommend the use of M_R as a fundamental material property in the flexible pavement design equation. Selecting a value of M_R that will best represent the resilient response of the subgrade is complicated by the many factors contributing to the stress response of the soil [2].

The AASHTO 1993 [3] recommends the use of an effective subgarde resilient modulus to account seasonal changes in resilient modulus. The effective subgarade soil resilient modulus is based on the widely accepted Miner's linier damage concept and utilized subgrade resilient modulus value from each of the primary moisture seasons. However, it desirable to determine an equivalent design season, or moisture condition, for which the corresponding resilient modulus reflects equivalent relative damage induced over the entire 12-month year. One of the approaches that can be used to estimates subgrade modulus based on deflections measured during non-destructive field test by Falling Weight Deflectometer (FWD) in different seasons of the years.

This paper is showing the result of the nondestructive data by using Falling Weight Deflectometer (FWD) that obtained from a Performance Evaluation of Flexible Pavement at Korea

Expressway Corporation Test Road. The purpose of this paper is to examine the NDT data provided by the Expressway & Transportation Research Institute - Korea Expressway Corporation (ExTRI KEC) study. A backcalculation program named ELMOD5 (Evaluation of Layer Moduli and Overlay Design), a backcalculation program developed by Dynatest that was supplied with the FWDs, was used to determine layer moduli. Backcalculation was performed for condition without a stiff layer in the different season from the Korea Expressway Corporation Test Road.

The test pavement used in this evaluation is located on The Korea Expressway Corporation Test Road (hereinafter KECTR), in Jungbu Inland Expressway (Central Inland Expressway), was planned in 1997 and construction finished in December 2003. After a pilot testing, it was officially open on March 24 2004. The KECTR, a two-lane and 7.7 km long high speed road, is compose of 25 concrete and 33 asphalt sections that were designed to develop Korean pavement design guide and to improve pavement technology. The AASHTO interim design guide (AASHTO 1972) was mainly used to design standard five sections selected for both concrete and asphalt pavements, and then additional design variable were considered to represent most of highway pavement in service. Figure 1 illustrates the pavement test section with measured material properties of asphalt concrete for pavement section A-2, A-7, A-11, and A-14. Those pavement sections have a uniform thickness of surface layer (50 mm) with material for surface is dense-graded asphalt (DGA). Materials for base consist of several types (black base type-5 or KHC designation BB5, black base type-3 or BB3, black base type-1 or BB1, and granular). On top on finished subgrade, subbase with 300 mm and anti-frost layer with varying thicknessess were placed, respectively.

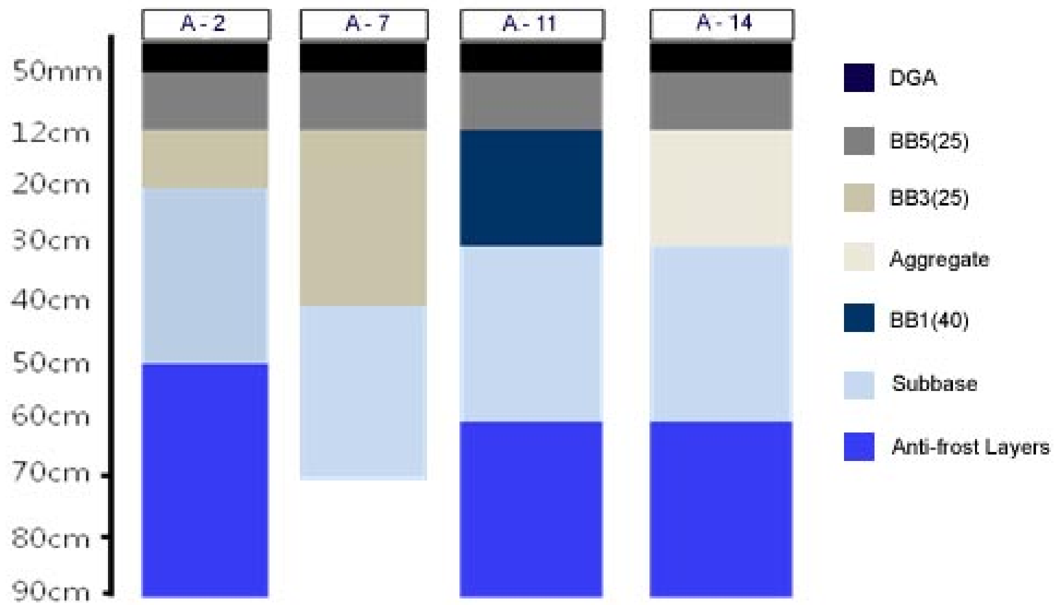


Figure 1 - Pavement Test Section at the KECRT

FWD deflection data was obtained with a Dynatest model 8000 FWD. Deflection basins were measured with sensor spacing of 0mm, 300mm, 600mm, 900mm, 1200mm, 1500mm, and 1800mm. The deflection measurements were taken at the exactly the same location and with the period that will be represented into four seasons in South Korea. Those deflection data that available were measured in August 2004, February 2004, April 2006, and June 2007. Unfortunately not all of those deflection data available can be used in the analysis for each observed segment. Deflection data on April 2006 cannot be used due to different FWD equipment used.

Average weather condition for KECTR was encountered for the testing period. Figure 2 illustrates the average air temperature observed from year 2004 to year 2007. It shows that variation of air temperature can be represented by a sine wave with a one-year period oscillating about a displaced base line, being the mean annual air temperature.

From Figure 2, it can be seen that deflection data on February 2004 can be represented for winter season with average air temperature was 1.6 °C. Deflection data on August 2004 represented for spring season with average air temperature was 25.6 °C. Deflection data on June 2007 represented for spring season with average temperature was 22.1°C.

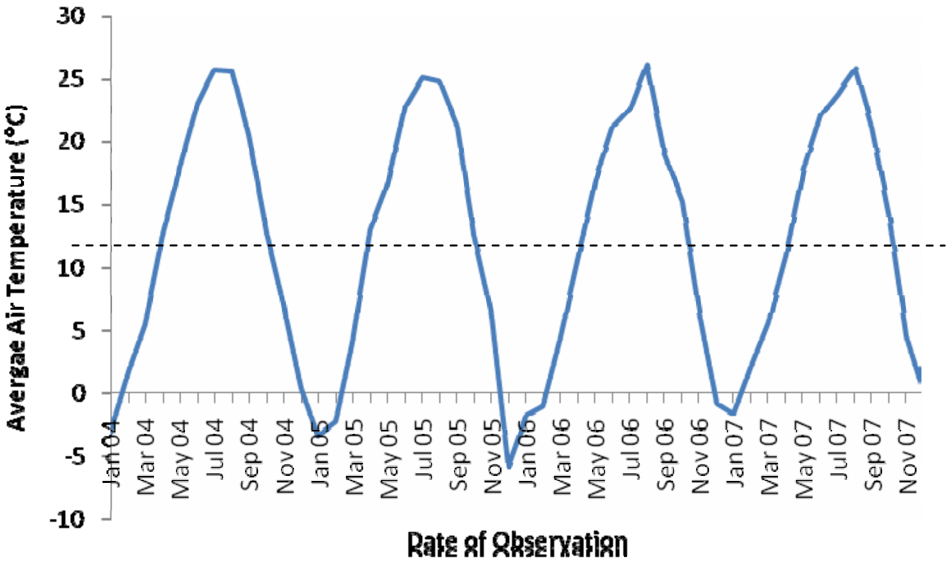


Figure 2 - Average Air Temperature in KECTR

2. COMPUTING ELASTIC MODULI

An elastic modulus, or modulus of elasticity, is the mathematical description of an object or substance's tendency to be deformed elastically (i.e., non-permanently) when a force is applied to it. Elasticity is a measured of how well a material returns to its original shape and size. Flexible pavements can be modeled as multilayered elastic systems. Each of the pavement layers can have its own plasticity parameters such as the modulus of elasticity and the Poisson's ratio. To estimate in situ elastic modulus for each pavement layer using a backcalculation approach by using nondestructive testing, i.e., commonly using the Falling Weight Deflectometer (FWD). The backcalculation procedure involves calculation of theoretical deflections under the applied load using assumed pavement layer moduli. These theoretical deflections are compared to measured deflections and the assumed moduli are then adjusted in an iterative procedure until the theoretical and measured deflection basins reach an acceptable match.

In this paper, the moduli of the pavement layers were calculated from the deflection basin measured during FWD tests by using ELMOD backcalculation program. ELMOD program uses an iterative process, where an initial set of layer moduli are assumed, the moduli are then used to compute surface deflections and these are compared to the measured deflections. The assumed moduli are adjusted, and the process is repeated until the calculated deflections match the measured deflections within some specified tolerance. This process is described in more detail by Lytton [4]. This approach has been found to be a good approximation to the generalized Burmeister equations under the following two conditions [5]:

- The layer thickness should be more than half the radius of the loading plate.
- The modular ratio of two adjacent layers (*Ei*/*Ei*+1) should not be less than 2.

Several assumptions were made in the backcalculation using ELMOD based on the elastic layer theory. These assumptions are follows:

- Surface load is uniformly distributed over a circular area.
- All layers are homogeneous, isotropic, and linearly elastic, except the subgrade which is assumed to exhibit non-linear response.
- Upper layers extend horizontally to infinity.
- Bottom layer is a semi-infinite half-space.

Based on the Odemark/ Boussinesq theory, backcalculation method is used in this program can only handle up to three independent layers. Therefore, pavement structure should be composed of three layer courses (surface, base, and subgrade). Different asphalt materials in pavement layer, such as wearing course, binder course and base course were combined into one layer. Second layer was assumed for the thickness between asphalt materials layer and subgrade. Last layer will be left blank, and would be assumed to correspond to the subgrade. In this evaluation, backcalculation was performed for condition without a stiff layer. Table 1 shows structure data that used in the computing elastic moduli using ELMOD5.

Table 1 – Structural Data of Test Road Segment in ELMOD Analysis

Section ID	Layer Thickness (cm)	
	Layer 1	Layer 2
A-2	20	70
A-7	30	40
A-11	30	60
A-14	12	78

To estimate moduli for pavement structure, the option of deflection basin fit in ELMOD5 is used with value of 1%. The theoretical deflection bowl for this pavement structure is calculated. The error between the measured deflections and calculated deflections is then assessed. The moduli in the structure are then increased/decreased by a small amount (typical 10%), and if the error in either of these deflection bowls is less than the original deflection bowl this is taken to be a better solution. This process is iterated until a minimum in error between the calculated and measure deflection bowls are found.

The estimate elastic moduli that calculated from ELMOD5 backcalculated result for each pavement section of KECRT are shown in Figure 2. Due to available data, estimated elastic moduli could not be calculated in representing for all of the season in KECTR as the goal of this paper. However, from the calculation can be shown that seasonal variations of elastic moduli were dependent upon layer thickness. From the presented data, Section A-2 can be used for representing for winter, summer, and spring season. Section A-7, A-11, and A-14 representing only for winter and summer.

3. OBSERVATIONS FROM BACKCALCULATION

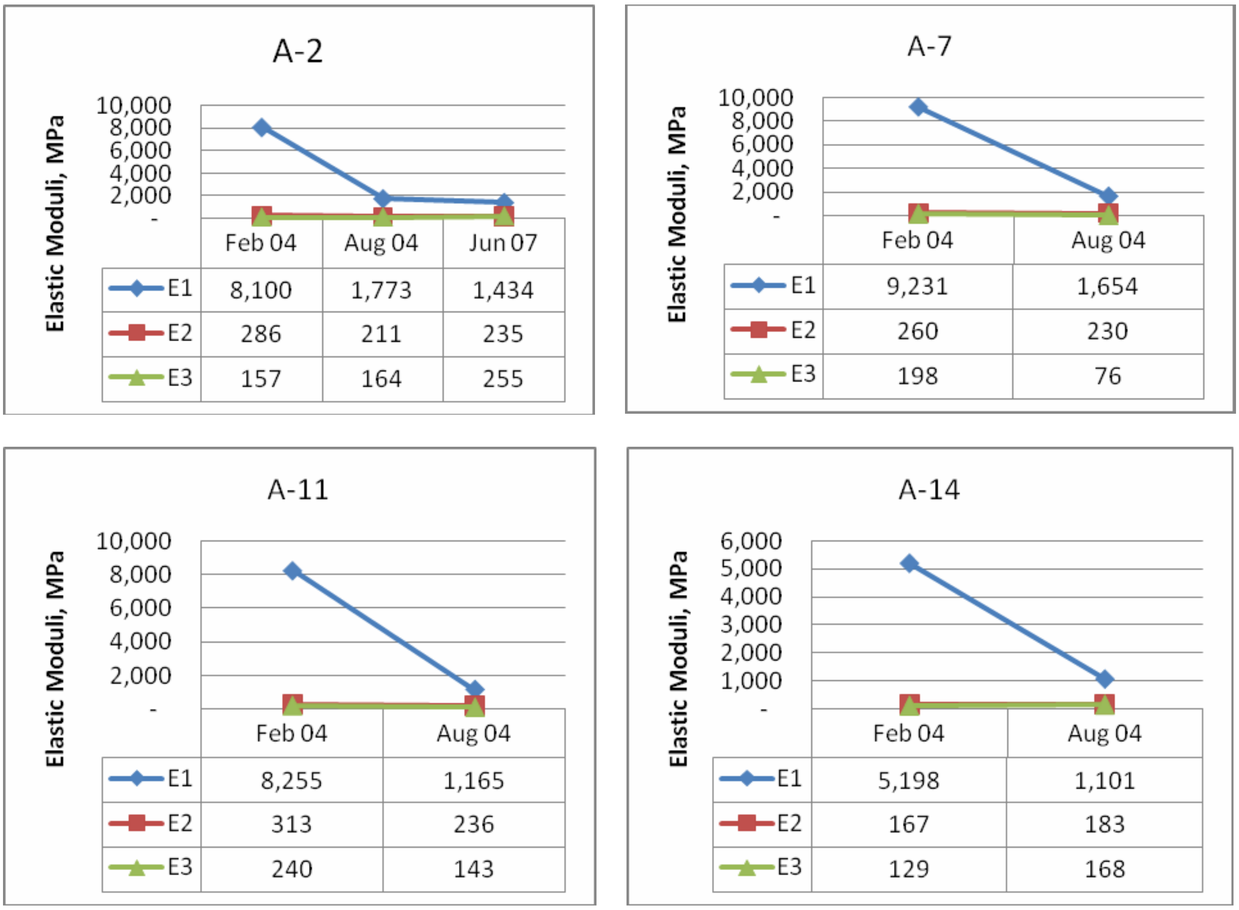
ELMOD5 backcalculation was used to calculate pavement layer modulus. Unfortunately, with the available data provided, it is difficult to make evaluation of the backcalculation. Then, the comprehensive observation cannot be done and will be limited. However, from this evaluation, it can be seen that the seasonal variations of elastic moduli are dependent upon layer thickness.

Result from ELMOD backcalculation for section A-2, A-7, A-11, and A-14 can be shown in Figure 3. Large decreases in surface layer moduli during freeze/ thaw condition for all type of section test. It was observed that large decrease in subgrade and base course moduli in section A-7 which have less thickness of base course than others or using frost resistance layer. M_R on winter season approximately 198 MPa and the reduced to 76 MPa in summer season. For other sections that have a thick base layer, such as A-2, A-11, and A-14, their resilient modulus became stable (slightly increasing or decreasing). It can be seen that the use of thick base course or frost resistance layer, in some cases, improved the performance of resilient modulus against the freeze/ thaw condition. It is one of the major concerns for the pavement design specially in the cold regions. Thawing can

reduces the strenght of the underneath layers while freezing creates frost haeving causing reduction in serviceability of the pavement.

The performance of resilient modulus against the freeze/ thaw condition may become imperative issue in the pavement design. Many studies have indicated that in the end of spring usually is the critical time for the deep-frost regions [6] [7]. For those regions, the spring thaw causes considerable increase in subgrade water content. For regions with a slight degree of frost, other times of the year may also be important.

Regarding for the seasonal variations, from previous study that performed by the Delft University of Technology, show pertinent indicative results [8]. It was shown that the variations of subgrade modulus can be represented by a sine wave with a one-year period oscillating about a displaced base line, being the mean annual subgrade modulus. This deficit is defined as the difference between precipitation and evapotranspiration. Ground water level of this section was rather static because of its location in a polder area with a controlled water regime.



Note:
E1 = elastic moduli for surface layer
E2 = elastic moduli for base layer
E3 =elastic moduli for subgrade

Figure 3 – Result of Elastic Moduli from ELMOD Backcalculation for section A-2, A-7, A-11, and A-14

Previous paragraphs made clear that subgrade resilient moduli is highly dependent on water content, which can vary significantly with a number of seasonal environmental factors. A pavement design based on this design season then should be assumed to reflect the seasonal variations in subgrade moduli and the corresponding relative damage that the pavement would sustain over all season of the year. This means that excluding seasonal effects in the pavement design can either

mask real deterioration, or can lead to unpredicted pavement lives. Therefore, in the purposes of pavement design, it is desirable to designate a design season that represents the equivalent damage for the pavement over a 12-month period. After the design season is established, only the resilient modulus corresponding to the design season condition must be determined for the design [2]. Therefore, the selection of an appropriate design value for M_R should reflect environmental effects on subgrade water content and the resulting pavement performance.

4. WEIGHTING FACTOR FOR SEASONAL RESILIENT MODULUS

One of the suggested procedures for determination resilient modulus of design season condition for subgrade soils under asphaltic concrete pavements is the weighted factor [9]. The weighting factor is used to estimate the mean annual air temperature, which represented the location effect. The design value of resilient modulus corresponds to periods when the weighting factor is equal to one. A pavement design based on this design season is assumed to reflect the seasonal variations in subgrade modulus and the corresponding relative damage that the pavement would sustain over all seasons of the year.

This approach may lead to a more cost-effective pavement design due to the design approach based on a resilient modulus corresponding to a water content somewhere between the seasonal maximum and minimum values. The derivation of the seasonal weighting factor was used to designate a design season condition, using NDT testing, was defined as

$$WF_i = \frac{12\, M_{Ri}^{-2.32}}{N \sum_{i=1}^{12} M_{Ri}^{-2.32}} \qquad (1)$$

and

$$M_{Ri} = C\,\frac{0.24P}{d_n\, r} \qquad (2)$$

where

P = applied load;

d_n = measured deflection at radial distance, *r*, for the i^{th} month;

r = radial distance at which the deflection, d_n, is measured;

C = an adjustment factor (a value of 0.33 is recommended by AASHTO).

Assuming the same equipment is used throughout the year for NDT testing, substitution of equation (1) into equation (2) yields

$$WF_i = \frac{12\, d_n^{2.32}}{\sum_{i=1}^{12} d_n^{2.32}} \qquad (3)$$

Therefore, the seasonal weighting factors can be determined by performing seasonal NDT tests throughout the year. NDT tests on pavement in different region across the region should provide a good estimation of design season conditions. Since the NDT using FWD is one element of estimating resilient modulus, then supplementary data must be collected simultaneously with the FWD deflection testing to evaluate the FWD result properly. Reliable resilient modulus can only be estimated with sufficient understanding of the effects of seasonal changes in temperature and moisture content on the pavement material properties. This applies not only to thaw-freeze regions, but also to zone with mild climates.

5. FINDINGS AND CONCLUTIONS

Evaluation of elastic moduli result from KECRT shows that the seasonal variations of elastic moduli are dependent upon layer thickness. Subgrade M_R is highly dependent on water content, which can vary significantly with a number of seasonal environmental factors. This evaluation indicate that the seasonal effect is certainly should not be negligible in determination of subgrade $M_{R.}$ Response and performance of flexible pavements are significantly influenced by the properties of the subgrade soil. Environmental conditions such as temperature, water content, and freeze-thaw effects have considerable influence on the measured subgrade M_R . It is important that the value of subgrade M_R in design represent the appropriate environmental condition. Many studies have been conducted to quantity the effect of variations in season on variations in load-carrying capabilities of asphalt pavement for the purpose of pavement design. One of the approaches that can be used is based on the weighting factor to quantify the effect of environmental conditions on the total life of a full-depth pavement. The seasonal weighting factors can be determined by performing seasonal NDT test throughout the year. NDT tests on pavement in different region across the region should provide a good estimation of design season conditions. Finally, the knowledge gained with this paper can be applied both in Korea or Indonesia to quantify selecting of effective subgrade M_R for flexible pavement design.

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